MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Laser Interferometer Gravitational Wave Observatory (LIGO) Project

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Subject: **Impact of anomalous N_2 outgassing from Viton seals**

I looked over the PSI Prototype Vessel Test Data Report (PSI V049-1-119) and wanted to communicate my assessment of their findings. First, it looks like the measurements and calibration methods are solid; I believe they actually saw anomalously large amounts of nitrogen, adsorbed (or absorbed) by the viton seals of both the BSC prototype vessel and by the loose 83 cm seal placed in their 10" test vessel. The BSC data are somewhat compromised by the fact that the backfill gas wasn't pure, but for the most part they appear consistent with the 10" test vessel results which were more controlled; I mostly looked at those.

The first observation (of course) is that we'd really like more data. My main uncertainties are related to the total quantity of gas adsorbed and to the rate at which it is taken up at one atmosphere. When they exposed the loose seal to 1 atm of N_2 for 24 hours, the subsequent outgas flux was about 14 times greater than when it had been exposed for only 1 hour; clearly at some point the seal must saturate. Maybe it had already, maybe not. Similarly, the data run only went 100 hrs, at which point it still appears to be going roughly as 1/T (although with some imagination one could be convinced it's getting weakly steeper). Obviously a finite reservoir of gas must reach depletion somewhere. This is interesting in itself just because of the amount of gas involved; I worked out that, after the 24 hour exposure, the gas evolved over 100 hours was equivalent to the contents of the o-ring's displaced volume backfilled to 10 torr (!), and a typical 4' or 5' flange o-ring will store about a torr-liter (i.e., like 300 cc-size virtual leaks per station). More to the point, our typical open time will exceed 24 hours and our typical operating time will exceed 100 hours. As a result any conclusions drawn now could be optimistic (in the sense that the 24 hour accumulation may not have been saturated) or conservative (in the sense that the 1/T trend can't persist forever).

The fact that N_2 is not condensible, and thus not pumped by the 80K cold trap, means the beam tube will reach equilibrium with the station as soon as the gate valves are open (actually the time constant is of order 6 hours, but the transient period doesn't concern us much at this level). The impact of the excess nitrogen's index fluctuations on detector sensitivity can be expressed as the time at which it crosses an allowable level as the pressure declines. The Science Requirements Document (SRD) noise level for the Initial LIGO Detector, at 150 Hz (the most sensitive frequency), is $\tilde{h}(150\text{ Hz}) \approx 2.5 \times 10^{-23}\ \text{Hz}^{-1/2}$, and the criterion for "technical" noise sources is that they each contribute less than 1/10 this amount to the noise budget.[1] Using this criterion, one gets the maximum allowable pressures for operation of the initial interferometer at "design sensitivity" shown in the fourth column of the table below. The initial LIGO pressure requirements and goals are shown in the second and third columns for reference.

Table 1: Partial pressure for residual gas phase noise = 1/10 SRD spectrum

gas	LIGO REQ (T)	LIGO GOAL (T)	P_{max} (T) [SRD/10]
H_2	1×10^{-6}	1×10^{-9}	2.5×10^{-7}
H_2O	1×10^{-7}	1×10^{-10}	2.3×10^{-8}
N_2	6×10^{-8}	6×10^{-11}	$\mathbf{1.5 \times 10^{-8}}$
CO_2	2×10^{-8}	2×10^{-11}	5×10^{-9}

Assuming a 1/T flux curve for each o-ring like the 24-hr exposure sample and PSI's spreadsheet scaling calculations, it appears the vertex section and BT manifold will reach the allowable partial pressure after approximately **two days** (PSI estimates a section partial pressure of 7×10^{-9} torr is reached after 100 hours). Taken by itself, this seems operationally inconvenient, but not crippling. Should trapped nitrogen continue to accrue with extended time at atmosphere, however, it could pose a threat to detector availability.

Looking beyond the first detector, as the sensitivity target improves by a factor of two the time to operating pressure will go up by a factor of four; so (assuming we succeed in reducing detector noise) we will have to do something eventually. This may take the form of distributed (getter, ion or sub-80K cryo) pumps along the beam tubes, additional station pumping, or retrofit of metal inner seals if this step has not been taken already. In my view the data we currently have don't by themselves warrant significant investment in these measures at this time. A repeat of the test, to find how long it takes and at what level the adsorption saturates when backfilled, would be useful in sealing this conclusion, and I'd like to try and get PSI to address this (perhaps as part of renegotiating the section acceptance criteria). In any case I feel we are covered against nasty surprises; after we get a few "real" pumpdown curves at Hanford there's still time to act (e.g., add a few small ion pumps on each beam tube module) before the detectors achieve design sensitivity.

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1. For historical reasons the beam tube and vacuum equipment specs are written to give 1/5 the SRD budget, not 1/10. This factor of two excess in strain contribution translates into a factor of four excess in pressure.

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